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APPLICATION OF LANDSAT DATA TO DELIMITATION OF AVALANCHE HAZARDS IN MONTANE COLORADO

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16. Abstract

The physical characteristics of the mountainous terrain in Colorado contain direct and indirect indicators of potential avalanche hazards. Many of these indicators should be detectable on LANDSAT imagery, but the spacial resolution of the system will almost certainly limit the ability to visually interpret them. Interpretation of small-scale (1:1,000,000) imagery is useful for determining the general location and distribution of avalanche hazards over a large region. Analysis of enlargement prints, however, provides additional detailed information for relatively small areas.

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PREFACE

Over the last several years, the Institute of Arctic and Alpine Research (INSTAAR) at the University of Colorado has been involved in the delineation, mapping, and analysis of natural hazards in selected portions of the Colorado Rocky Mountains. Much of this research has been concerned with the detailed delineation of snow avalanche hazards using air photo and field mapping techniques. Continuous monitoring of various environmental parameters during the winter avalanche cycle has produced significant advances in the field of avalanche prediction and forecasting for local areas.

In June 1975, INSTAAR began research for the National Aeronautics and Space Administration (NASA contract NAS5-20914) on a new approach to avalanche hazard investigation. The purpose of this research is to analyze, evaluate, and apply LANDSAT imagery for delineating and mapping avalanche hazards in the Colorado mountains. Research is currently being directed toward six primary objectives:

(1) Compilation and analysis of historical avalanche records for cause/effect and frequency information.

(2) Identification of avalanche hazard terrain characteristics detectable on LANDSAT imagery.

(3) Determination of relative usefulness of LANDSAT imagery for avalanche hazard mapping.

(4) Determination of useful schemes for cartographically representing avalanche hazards.

(5) Using the synoptic and repetative aspects of LANDSAT imagery for regional avalanche hazard mapping and analysis.

(6) Examining the cost/benefits of avalanche hazard investigations.

Secondary, and purely experimental, objectives of the research project are as follows:

(1) Investigation of potential usefulness of LANDSAT derived information as input to avalanche forecast or warning systems.

(2) Investigation of the usefulness of LANDSAT imagery for mapping major landslide areas.

During the report period (1 June-31 August), funded research was conducted by one full-time research staff member. Additional research, not directly funded by the project, was conducted by several research staff members and graduate student assistants. Research conducted during this report period has shown that:

(1) although comprehensive compilation of avalanche hazard data on a state-wide basis appears to be beyond the scope and funding of the project, the acquisition and analysis of these data will be persued to the fullest possible extent,

(2) terrain characteristics indicative of avalanche hazard areas can be interpreted on LANDSAT imagery,

(3) interpretation of small-scale LANDSAT imagery allows the general location and distribution of avalanche hazards to be determined, and

(4) more detailed information can be extracted from enlargement prints than from small-scale imagery alone.

Because of changes in personnel and redelegation of research responsibilities, it is recommended that Dr. Daniel H. Knepper replace Dr. Jack D. Ives as Principal Investigator for the project, and that Dr. Ives, as director of INSTAAR, be designated the Project Manager.

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INTRODUCTION

This report summarizes the work conducted by the Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, during the period 1 June - 31 August 1975, under contract NAS5-20914 to the National Aeronautics and Space Administration/Goddard Space Flight Center.

During the report period, contacts were established with various state and federal agencies and other avalanche hazard investigators to determine the amount, nature, and availability of avalanche records for the Colorado Rocky Mountinas. Potentially useful criteria for identifying avalanche hazard areas on LANDSAT imagery were identified. A first-look evaluation of the avalanche hazard information contained in LANDSAT imagery was conducted, and initial, experience-gaining, attempts at avalanche hazard mapping on small- and large-scale LANDSAT imagery products were made.

ORGANIZATION

Much of this first report period was spent acquiring background information and searching for references pertinent to the application of LANDSAT imagery to avalanche hazard research. In addition, the direction and schedule of the major research objectives were defined, and initial contacts with other avalanche hazard investigators in the region were established.

Since 1 July, Dr. Dani Knepper has been in charge of the research conducted on this project. Since Dr. Knepper has the research responsibility, we feel that he should be designated the NASA Principal Investigator, replacing Dr. Jack Ives. As director of INSTAAR, Dr. Ives would become the Project Manager. A formal letter requesting these changes has been sent to our NASA Technical Monitor, Mr. James Broderick, at Goddard Space Flight Center.

In September, a graduate student research assistant will be added to the funded project staff.

COLORADO AVALANCHE DATA

During the report period, various state and federal governmental agencies were contacted to determine the amount, nature, and availability of avalanche records for the Colorado Rocky Mountains. The following statements summarize the status of Colorado avalanche records:

(1) No comprehensive data on the location, occurrence, and classification of Colorado avalanches has been compiled.

(2) The location of major avalanche hazards that yearly affect highways, winter recreation areas, mines, and cities and towns are known, but no systematic records of avalanche occurrence and classification have been made.

(3) There are virtually no known records of the avalanches occurring in the mountain backcountry, except for a very few that have caught or killed an occasional hunter or skier.

(4) The occurrence of large avalanches resulting in death or extensive property damage are commonly reported in local newspapers.

(5) A few select areas have been monitored over a short period (days or weeks); the most extensive avalanche data for a single area were collected by INSTAAR during the three-year San Juan Avalanche Project, covering the area along U. S. 550 between Coal Bank Hill and Red Mountain Pass (1).

(6) Potentially the largest single source of avalanche data is the recollections of the mountain residents, however, these data are difficult and time-consuming to obtain and are often colored by their personal experiences.

In summary, the search for and the systematic compilation of Colorado avalanche data on a state-wide basis appears to be outside the scope and funding of this project. However, since these data can provide a means, often the only means, of determining the characteristics and frequency of avalanches in specific areas, we will attempt to gather this information for selected areas defined as LANDSAT imagery mapping progresses. Instead of a preliminary phase of this investigation, then, the compilation and analysis of Colorado avalanche data will be continued throughout the project and will be limited by the project funding and duration.

IDENTIFICATION CRITERIA

The purpose of this investigation is to delimit avalanche hazards, so we must develop some criteria that will enable us to distinguish between avalanche and non-avalanche areas. Moreover, these criteria must be expressed on LANDSAT imagery as recognizable tonal and textural patterns.

As part of Phase I of this investigation, some tell-tale characteristics of known avalanche paths that may be recognizable on LANDSAT imagery have been defined,and terrain conditions that may suggest avalanche hazard potential in areas where direct evidence of past avalanche activity is lacking have been outlined.

AVALANCHE TERMINOLOGY

An avalanche path consists of three basic parts: release zone, track, and runout zone. The release zone, or starting zone, is where a volume of snow breaks loose from the more stable snowpack and begins its descent down slope. The evolution of unstable snowpack is the result of the interaction between several processes, most of which are related to radiation, temperature, snowfall, and wind conditions. An excellent discussion of the physical causes of avalanches in the San Juan Mountains of southwestern Colorado is contained in (1).

The major portion of the downslope movement of avalanching snow occurs in the avalanche track. Avalanche tracks vary widely in size and shape, and are of considerable importance in estimating the degree of

avalanche hazard in a given area. Many large avalanche paths are characterized by tracks contained within a linear or curvilinear topographic depression oriented downslope. These gully avalanches tend to focus the destructive energy of the moving snow towards a relatively small area at the bottom of the avalanche path. Equally dangerous, though more difficult to identify, are avalanche tracks on unconfined slopes. Because the avalanching snow on unconfined slopes is not centrally focused, the associated avalanche hazard area may be quite extensive compared to the length the avalanche has run.

The avalanche <u>runout zone</u> is the area where the snow, rocks, soil, trees, and other debris moved by the avalanche finally come to rest. The size and shape of the runout zone are directly related to the size and shape of the associated track, although the topographic configuration of the runout zone may exert considerable influence on the detailed area covered by avalanche runout.

A fourth zone, the <u>airblast zone</u>, may sometimes be recognized around the runout zones of high velocity, powder avalanches. Airblast is a gust of wind produced by the movement of avalanching snow that may extend outward from the runout zone for considerable distances. The airblast zone can only be determined from its effects, primarily destructive, on the terrain. Zones of airblast must always be evaluated in determining the avalanche hazard of an area.

There are two basic types of avalanches: loose snow and slab. <u>Loose snow</u> avalanches originate in snow lacking internal cohesiveness, generally from a point on the slope with a tendency to fan-out as they move downslope. Loose snow avalanches are generally smaller and less destructive than slab avalanches, although they are more numerous.

Slab avalanches are characterized by the simultaneous release of a single slab or block of snow along a well-defined fracture at the upper boundary of the slab. Subsequent to the initial release, the slab begins to break up into smaller and smaller fragments. If the cohesion of the snow is slight, only powder and small blocks will be preserved in the runout zone. This is characteristic of a soft slab avalanche. A hard slab avalanche contains large blocks of the original slab in the runout zone.

Avalanches may also be classified as wet or dry, depending on the presence or absence of water in the unstable snowpack. Wet snow avalanches, both loose snow and slab, tend to be smaller and slower than corresponding dry snow avalanches, but wet snow avalanches have considerable destructive potential, even at lower velocities, because of the relatively high density of the snow.

DIRECT AVALANCHE HAZARD INDICATORS

The problem of delineating avalanche hazard areas involves two types of analysis. The first is concerned with identifying those areas in which avalanches can be shown to have run in the past and, therefore, will probably run again in the future. We must be able to identify characteristics of the terrain that are the direct consequence of avalanching so that the extent of past (and future) avalanche hazards can be estimated. Direct indicators of past avalanche activity can be grouped into two main catagories: (1) snow characteristics and (2) vegetation patterns.

Snow Characteristics

A snow characteristic is an identifiable appearance or distribution of the snow caused directly by avalanching. Several different types of snow characteristics should be detectable on LANDSAT imagery.

Patches of snow that persist into late spring or early summer, particularly at the base of slopes or at breaks in slope, commonly result from an above average accumulation of snow in avalanche runout zones. The remnant snow patches should be in sharp spectral contrast with the surrounding snow-free terrain, so even relatively small patches may be detectable on LANDSAT imagery. Identification of remnant snow patches on forested slopes may provide an important means, perhaps the only means, of delimiting avalanche hazards in forested terrain.

Linear belts of persistent snow oriented downslope should also be thoroughly studied. They may represent greater-than-average snow accumulations within large avalanche tracks due to successive small avalanches that fail to run to full track. Or, they may exist because they are sheltered from the melting affects of wind, rain, and solar radiation by the topographic configuration of gully-type avalanche tracks.

Actual changes in the character of the snow caused by avalanching during the winter avalanche cycle are rather quickly subdued by wind and subsequent snowfall. Yet, if LANDSAT imagery is acquired only a short time after avalanching, it may be possible to detect patterns of disturbed snow (ridges, grooves, blocks). The disturbed, roughed-up, snow should have overall radiance values somewhat below (darker tone) the undisturbed snow because of microshadows produced by low sun-angle illumination. The aspect angle between the sun and the general terrain slope and the

size and "roughness" of patches of disturbed snow will be critical factors in determining whether this phenonmenon will be detectable on LANDSAT imagery. Similarly, a fracture line scarp produced by slab avalanche release may also be selectively shadow enhanced by low sun-angle illumination, although the actual detection of such a fracture line on LANDSAT imagery will probably be a rare event.

In the spring, the snow surface acquires wind-transported dust and silt, effectively lowering the albedo of the snow, so that when spring avalanches run, they expose clean snow along their paths. The contact between the dirty, undisturbed snow and the clean snow in the avalanche paths is easily detected in the field and on air photos and may be detectable on LANDSAT imagery.

<u>Vegetation Patterns</u>

Avalanches commonly have a profound affect on the location and distribution of vegetation, and this relationship provides a powerful and generally applicable set of identification criteria. Perhaps the most conspicuous vegetation pattern attributable to avalanches is the <u>trimline</u>. A trimline is a sharp break in vegetation caused by the reduction or removal of the natural vegetation within an avalanche path. Trimlines are most obvious where avalanches have cut a swath through mature coniferous forests. The boundaries between forest and forest-free areas are readily detectable on snow-free LANDSAT imagery, and in many cases are enhanced by moderate snow cover.

Avalanche paths stripped of the larger forms of vegetation may become revegetated if large, full-track avalanches run only infrequently. In the Colorado Rocky Mountains, revegetation of avalanche paths cut through

coniferous forests is most commonly by aspen (populus tremuloides). Aspen intergrown with conifers can be readily discriminated on spring and summer LANDSAT imagery because of their markedly different reflectances in the photo-infrared portion of the electromagnetic spectrum. However, the overall pattern of these vegetation intergrowths must be carefully evaluated because aspen reforestation can be triggered by phenomena other than avalanches.

Occasional recurrence of avalanche activity may produce several stages of aspen reforestation that can be detected in the field by differences in tree height and crown diameter. Aspen stands of different ages can also be discriminated on air photos by their different crown densities, and discrimination may be possible on LANDSAT imagery if the separate stands are large enough.

An avalanche may move through forested terrain without removing the trees, although some tree damage may occur. Similarly, trees may be damaged along the lateral margins of avalanche paths and in airblast zones. The damaged trees may be less vigorous than surrounding undamaged trees, and this condition can often be detected on infrared film because the stressed trees have lower photo-infrared reflectances than unstressed trees of the same species. These reflectance differences should be detectable with LANDSAT sensors, but the areal extent of tree damage may be too restricted to resolve on the imagery.

INDIRECT AVALANCHE HAZARD INDICATORS

The second, and most difficult, type of avalanche hazard analysis involves the identification of areas in which avalanches may occur in the future, but which cannot be shown to have been active in the past. These areas contain no direct indicators of past avalanche activity such as trimlines and debris fans. In the context of LANDSAT imagery, they are areas in which direct indicators, if present, cannot be detected and identified.

Indicators that suggest the possibility of avalanche hazard are of two types: (1) topographic and (2) vegetative.

Topographic

No single topographic feature is indicative of possible avalanche hazard. To the contrary; landform analysis that considers the sum of many topographic phenomena is necessary to confidently define potential avalanche hazard areas. Comparison of the topographic character of active avalanche areas with "unknown" terrain is an invaluable interpretive aid.

The following is a general list of the topographic factors of the terrain that must be evaluated:

(1) slope angle - steep enough to promote movement, but gentle enough to allow the accumulation of snow; 30^{o} to 45^{o} slopes most common.

(2) slope aspect - the orientation of the slope with respect to the sun and prevailing winds.

(3) relief - the potential vertical drop.

(4) slope profile - both longitudinal and transverse should be evaluated.

Vegetative

The absence of substantial vegetation, whether natural or artificial may indicate a potential for avalanching. Isolated patches of vegetation-free ground on otherwise well-vegetated slopes may mark potential avalanche starting zones characterized by yearly, greater-than-average snow depths. Deforestation caused by forest fires, is a particularly important aspect of avalanche hazard analysis because it may produce an avalanche hazard in an area that was previously considered safe. Completely non-forested slopes must be studied very carefully, since the absence of trees may contribute to the instability of the winter snowpack. The absence of trees, however, is not sufficient for defining an avalanche hazard area; vegetation anomalies must be evaluated in relation to the topographic configuration of the terrain.

AVALANCHE HAZARD MAPPABILITY

Preliminary avalanche hazard mapping at both large and small scales was conducted to acquire a working knowledge of the image expression of various avalanche hazard indicators (see IDENTIFICATION CRITERIA, this report) and to get an initial indication of the mappability of avalanche hazard areas on LANDSAT imagery. The mapping was done by two investigators using somewhat different data products and interpretation equipment and techniques.

SMALL-SCALE MAPPING (R. SUMMER)

LANDSAT black and white, positive transparencies (1:1,000,000) covering the San Juan Mountains of southwestern Colorado were interpreted for avalanche paths. Interpretations were made stereoscopically when suitable sidelap imagery was available, and pseudostereoscopically, using bands 5 and 7 of the same image set as a stereopair, for the remaining coverage. The mapped avalanche hazards (Figs.1 and 2) are avalanche paths recognized by the presence of direct avalanche hazard indicators such as trimlines. No special attempt was made to determine the avalanche hazard potential of areas where direct indicators could not be recognized.

Four sets of available LANDSAT imagery were first examined to determine which imagery would most likely provide the greatest amount of information and to study the characteristics of imagery acquired at different times of the year. A summary of this first-look evaluation is given below.

IMAGE I.D.	DATE	COMMENTS
1317-17204	June 1973	Avalanche tracks mappable along streams (Aninas River, Cement Creek), but upland areas are snow covered and difficult to interpret. Many tracks mappable by trimlines.
1299-17205	May 1973	Similar to 1317-17204, but image definition is sharper; more details can be interpreted.
1461-17181	October 1973	Very little snow. Many tracks seen on May and June imagery not detectable. Tracks marked by trimlines mappable.
1173-17202	January 1973	South-facing slopes oversaturated (white out); north-facing slopes in shadow. A few tracks discernable.

Two regions of the San Juan Mountains were then selected for more detailed analysis and avalanche hazard mapping: (1) west-central Hinsdale and northwestern Mineral counties and (2) San Juan County.

West-Central Hinsdale and Northwestern Mineral Counties

Avalanche paths interpreted from LANDSAT image 1173-17202 were transferred to a 1:250,000 topographic map (Durango sheet) using a Bausch and Lomb Zoom Transfer Scope (Fig. 1). The large paths are outlined by solid lines to indicate relatively sharp boundaries and by dotted lines to indicate questionable interpretations. In some instances, the entire area of an

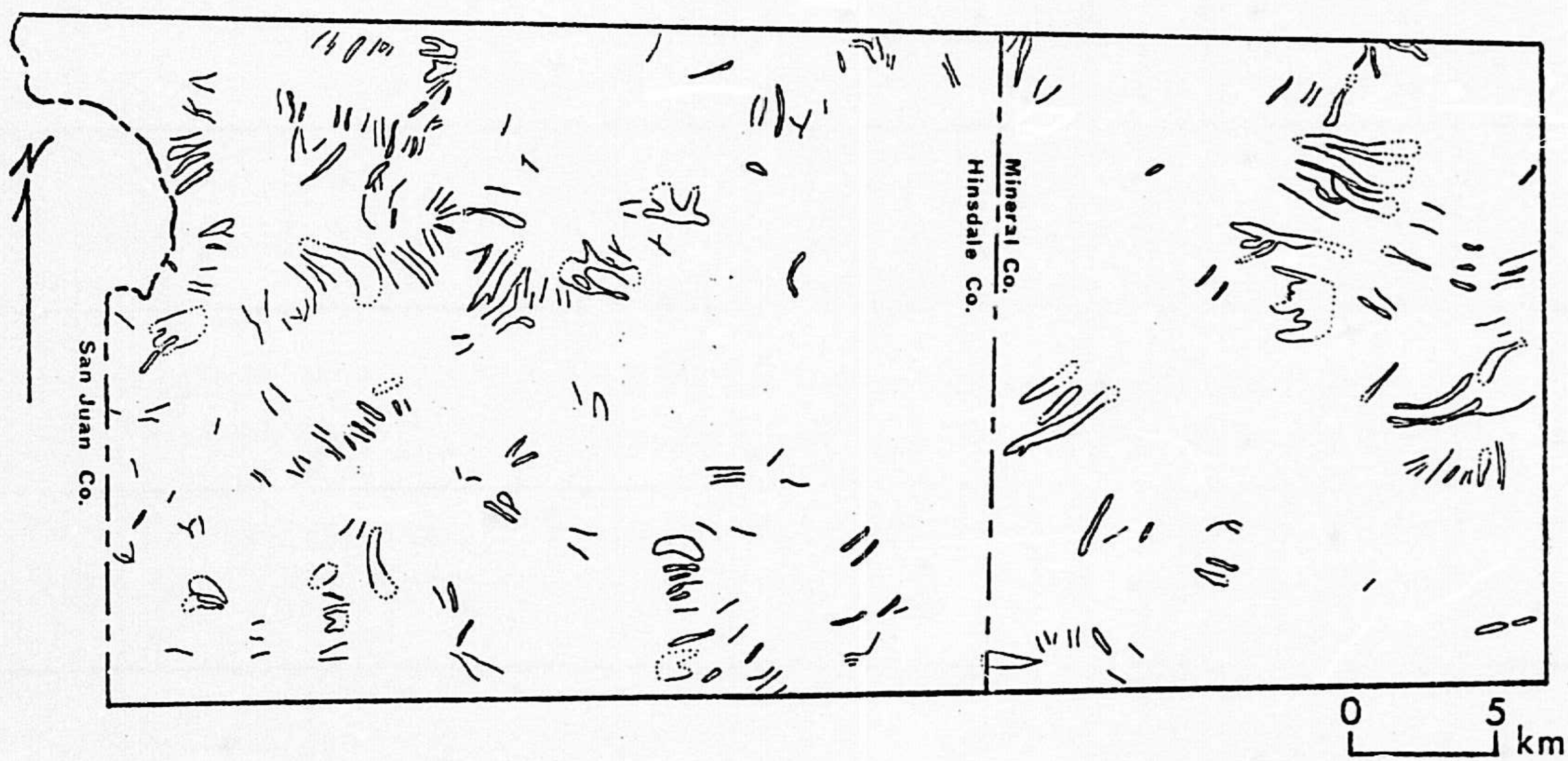

Figure 1. Avalanche hazard photointerpretation of small-scale LANDSAT image 1173-17202 over west-central Hinsdale and eastern Mineral counties, southwestern Colorado. See text for explanation.

avalanche path could not be determined, so the path was only partially outlined. Small avalanche paths are shown with a single solid line.

Both band 5 and 7 images were interpreted. Band 5 has somewhat better contrast, making the boundaries of avalanche paths easier to map. But less than 2 percent more paths could be mapped on band 5 than on band 7 imagery.

In order to obtain a first approximation of the capabilities and limitations of avalanche mapping on LANDSAT imagery, the LANDSAT-mapped avalanche paths in the area covered by the Pole Creek quadrangle (1:24,000) were compared to an avalanche map of the quadrangle prepared by photointerpretation of color infrared photos (1:30,000) acquired on NASA missions 239 and 247. A total of 108 paths were mapped on the photos and 86 on LANDSAT imagery. Of the 86 paths mapped on LANDSAT, 24 were <u>not</u> mapped on the photos because there were no direct avalanche indicators.

If we assume that the avalanche paths mapped on the large-scale color infrared photos represent the actual number and location of the paths in the area, then the results of the LANDSAT imagery interpretation can be summarized as follows:

(1) 57 percent (62/108) of the avalanche paths in the Pole Creek quadrangle were correctly identified and mapped.

(2) 72 percent of the avalanche paths mapped on LANDSAT imagery were actually avalanche paths, and 28 percent were incorrectly identified as avalanche paths.

<u>San Juan County</u>

San Juan County avalanche paths interpreted from LANDSAT image 1299-17205 are shown in Figure 2. Map symbols are the same as Figure 1.

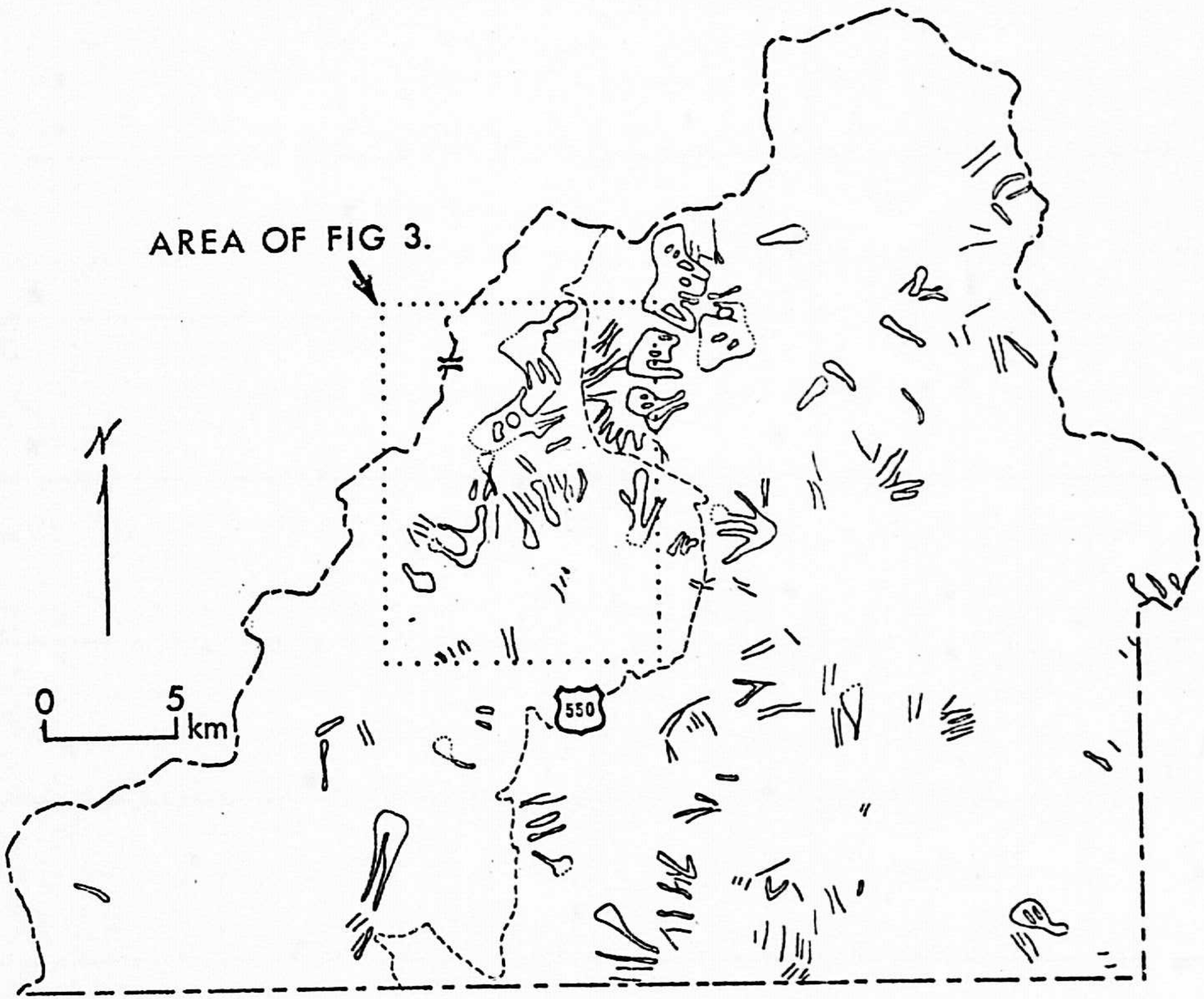

Figure 2. Avalanche hazard photointerpretation of small-scale LANDSAT image 1299-17205 over San Juan County, southwestern Colorado. See text for explanation.

The LANDSAT-mapped avalanche paths in the area of the Howardsville quadrangle (1:24,000) were compared to an avalanche hazard map of the quadrangle prepared from color infrared photos (1:30,000) acquired on NASA mission 247. A total of 134 paths were identified on the photos and 22 on the LANDSAT imagery. Of the 22 mapped on LANDSAT, 4 did not correspond to any path interpreted on the photos and, therefore, might be considered to have been misinterpreted. Again, if we assume that the photo interpretation map is "ground truth" for the area, the LANDSAT imagery mapping can be summarized as follows:

(1) 13 percent (18/134) of the avalanche paths in the Howardsville quadrangle were detected and mapped on LANDSAT imagery.

(2) 82 percent (18/22) of the LANDSAT-mapped paths were correct and 18 percent were incorrectly identified.

LARGE-SCALE MAPPING (D. KNEPPER)

Examination of the 1:1,000,000-scale, black and white, positive LANDSAT transparencies of the western San Juan Mountains indicated that there is more avalanche information in the imagery than can be suitably annotated. To obtain an idea of the capability for detailed avalanche hazard mapping, 18X enlargement prints (1:185,000) were prepared from 70mm negatives of the Silverton-Telluride-Ophir area, using images 1461-17181-7 (October 1973) and 1173-17202-7 (January 1973) to give basic coverage at contrasting times of the year. Complete stereoscopic coverage of the area was obtained with prints made from following-day images 1462-17235-7 and 1174-17261-7, respectively. The 70mm negatives used to make the prints are extremely dense and produced poor, but usable, prints.

The prints were analyzed for avalanche hazard information using a pocket stereoscope (3X) with all annotations being made directly on the October imagery. The LANDSAT interpretations were then compiled on topographic base maps (1:62,500) of the Silverton and Telluride quadrangles, using a Bausch and Lomb Zoom Transfer Scope. Figure 3 is a portion of the total area mapped.

This large-scale mapping has not yet been evaluated for accuracy and completeness, however, an indication of the utility of using enlarged prints for interpretation and annotation can be seen by comparing Figures 2 and 3. It appears that additional detail can be extracted from the enlargements.

Three major avalanche hazard mapping catagories were used during large-scale LANDSAT interpretation. The first catagory (dotted pattern) is large avalanche paths interpreted on the basis of tentative identification of <u>direct</u> avalanche hazard indicators, supplemented by indirect indicators, especially topographic configurations. The downslope ends of these paths have been left undefined because runout zones could not be satisfactorily interpreted on the poor quality prints.

The second avalanche hazard catagory, shown by a dot-dash line terminated with an arrowhead, is avalanche paths too small to outline. These paths were interpreted on tonal and textural patterns suggestive of direct avalanche hazard indicator criteria.

The third catagory (open) is areas of potential avalanching based on indirect avalanche indicator criteria only. Dotted arrows in these areas show the probable direction of snow movement as interpreted from the LANDSAT imagery.

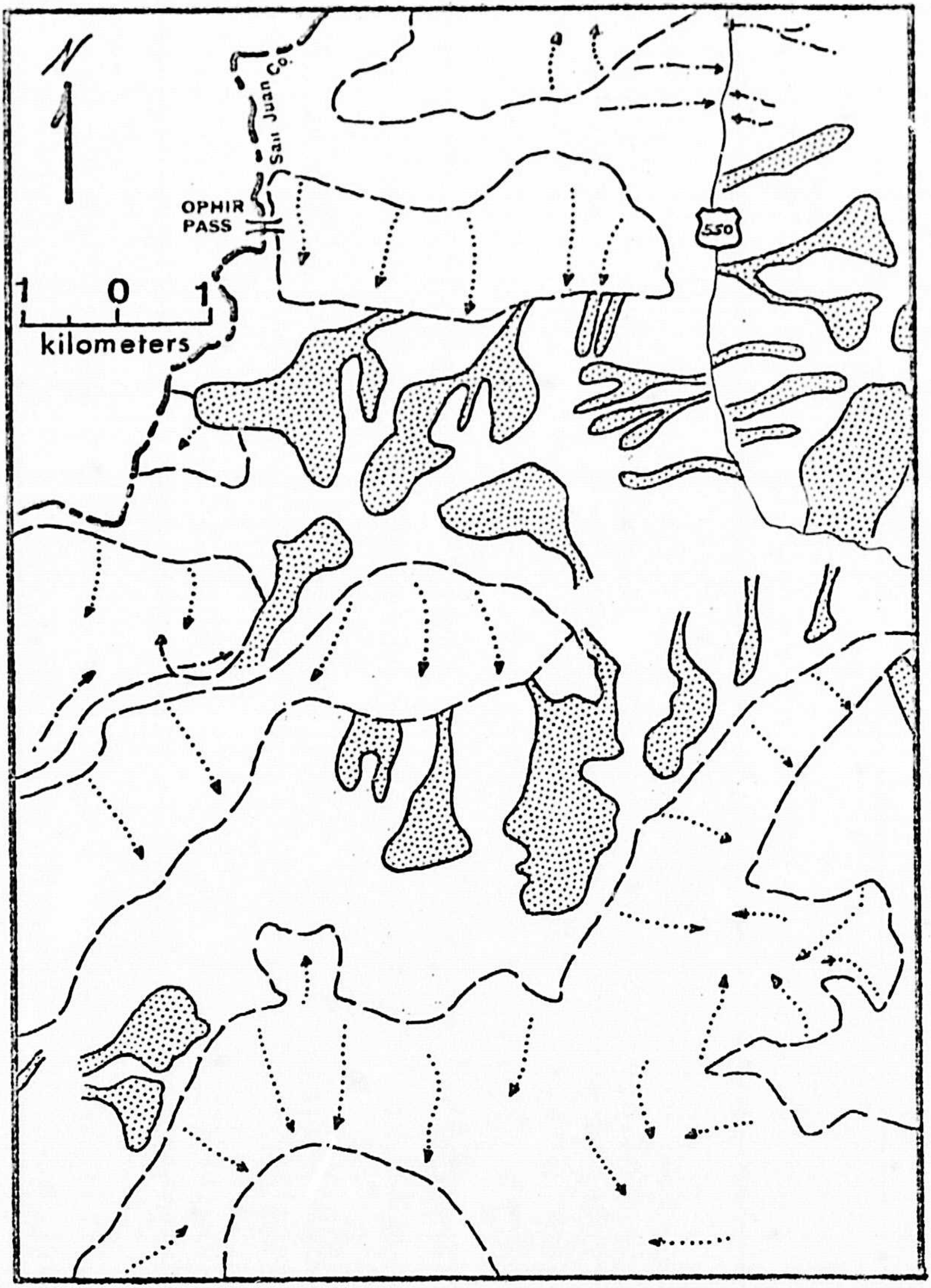

Figure 3. Avalanche hazard photointerpretation of large-scale LANDSAT images 1173-17202-7 and 1461-17181-7, combined. See text for explanation.

During the next report period:

(1) The accuracy and completeness of this preliminary large-scale mapping will be evaluated.

(2) High quality enlargement prints will be prepared.

(3) The area will be reinterpreted using new sets of imagery.

(4) The usefulness of pseudoscopic analysis of enlargement prints will be evaluated.

(5) The imagery expression of several known avalanche paths will be studied to refine criteria for identifying avalanche hazard areas.

PROGRAM FOR NEXT REPORT PERIOD

During the next report period, the work begun during this period will be extended and several new lines of investigation will be initiated. The following list summarizes the direction of the project for the next three months:

(1) Continue search for avalanche hazard references.

(2) Compile and analyze available historical avalanche data for selected areas in the San Juan Mountains.

(3) Refine the list of avalanche hazard identification criteria presented in this report. This work will involve detailed analysis of LANDSAT imagery and the preparation of a catalogue illustrating the LANDSAT imagery, air photo, and ground appearance of avalanche hazard indicators. This work will continue through the duration of the project.

(4) Photointerpretation of large- and small-scale LANDSAT imagery will be geared towards preparation of a preliminary avalanche hazard map of the San Juan Mountains.

(5) Preliminary experiments with the preparation and interpretation of enhanced LANDSAT imagery for avalanche hazard detection will be conducted. The enhancement techniques to be tested are density slicing and color additive viewing.

CONCLUSIONS

1. Interpretation of small-scale LANDSAT imagery provides a means for determining the general location and distribution of avalanche paths. However, the accuracy and completeness of small-scale mapping is less than is obtained from the interpretation of large-scale color infrared photos.
2. Interpretation of enlargement prints (18X) of LANDSAT imagery is superior to small-scale imagery because more detailed information can be extracted and annotated.
3. The systematic compilation of avalanche hazard data on a state-wide basis appears to be beyond the scope and funding of this project. However, we will continue to collect and analyze these data at the highest rate possible.
4. Many physical features indicative of avalanche hazard should be detectable on LANDSAT imagery; several have already been identified during preliminary imagery analysis.

RECOMMENDATIONS

1. That Dr. Daniel H. Knepper replace Dr. Jack Ives as Principal Investigator of NASA Contract 20914.
2. That Dr. Ives, as director of INSTAAR, be designated the Project Manager.

FUNDS EXPENDED

Total project expenditures are as follows: $1188.74.

DATA USE

Value of Data Allowed	Value of Data Ordered	Value of Data Received
$1,148	$ 579	$ 147

NEW TECHNOLOGY

No new technology was developed during the report period.

PUBLICATIONS

No project-funded publications were prepared during this report period.

REFERENCES

1. R. L. Armstrong, E. R. LaChapelle, M. J. Bovis, J. D. Ives. Development of Methodology for Evaluation and Prediction of Avalanche Hazard in the San Juan Mountain Area of Southwestern Colorado. Institute of Arctic and Alpine Research Occasional Paper 13, Boulder, Colorado, 1974. 141 pp.